

# COTS Electronics in Space - COTS Technology Panel -

Mark White

Philippe Adell

Melissa Meyers

Elaheh Rabiei (UCLA)

Mihai Diaconeasa (UCLA)

# The Big Picture

- NASA has been directed to develop a plan for an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system, returning humans to the moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.
- While it remains unclear what role JPL will play in this vision, the use of COTS H/W in our missions will become more commonplace.
- It is imperative we continue to study and understand the risk of inserting COTS technologies into our hardware.





# Modeling for COTS Electronics in Space Systems

Space systems designs are trending towards using ever more high commercial performance electronics

Commercial electronics represent an ever higher fraction of a system's part inventory

Testing parts for every part type will be too costly and not practical

➡ Modeling practices to support “virtual assessment” from part to system

## Anticipated results

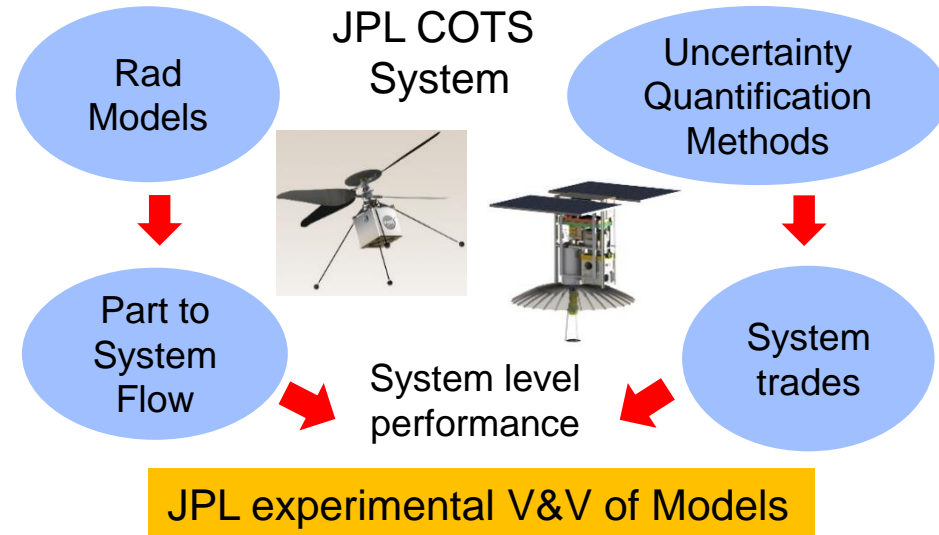
First development of a “virtual assessment modeling framework” for Commercial-Off-The-Shelf (COTS) systems

*New process development within 5X that will benefit JPL missions*

## Applications:

Short term: Sub-systems and systems

Long term: JPL CubeSats/SmallSats/Class D



## A strategic long term partnership

**JPL is leveraging simulation capabilities investment at SNL**

SNL updates own tools to accommodate JPL care-about

**SNL lacks our system level reliability trades capabilities**

SNL is funded to support this collaboration

Joint product: Transistor to  
Spacecraft Reliability

# High-Level Goals

- **Aid design decision throughout the project life cycle**
- **CubeSats provide the initial test cases, Class B missions are the future targets**
- **Tailor model fidelity to project risk posture and design maturity**
- **Low fidelity models:**
  - not quantitative and use generic and/or best guess reliability information
  - comparative to support system architecture studies and fault protection
  - informing the user of key risk drivers
  - very fast! Spacecraft models created in weeks. Scenarios executed in minutes.
  - most likely users are proposals teams, system engineers
- **High fidelity models:**
  - are multi scale and have the ability to model piece parts and entire spacecraft
  - use test data, physics based simulation results, lookup tables, heuristics, etc.
  - are quantitative and estimate level of confidence (UQ, Monte Carlo, ...)
  - most likely users are reliability and radiation specialists at JPL
- **Provide an integrated framework for reliability estimation of COTS devices considering both qualitative and quantitative information, when little or no test data are available.**

# JPL COTS Parts Risk & Reliability


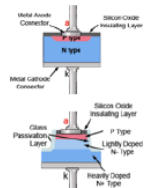

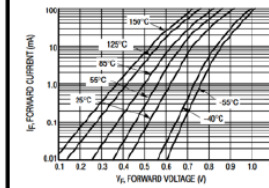
## User & Application Guide

- **JPL Guideline:** ‘Commercial Off-The-Shelf (COTS) Parts Risk & Reliability User & Application Guide’ (Dec. 2017)
  - ***Screening at higher levels of assembly (PCB, System Level) will become more prevalent with the infusion of the latest COTS parts.***
    - Scaling trends and reliability concerns for different CMOS applications
    - Effect of processing variations on reliability
  - *For many VLSI/ULSI devices, particularly those optimized for speed, the junction temperature must be restricted to lower ranges than for previous generations and technology nodes.*
  - *Raising the burn-in temperature may not only be risky, but may also increase the chance of inadvertent thermal runaway during burn-in.*
  - *It is also possible for undetected transients during burn-in to damage good devices, increasing the chances of “walking wounded” devices being used in the flight lot.*
  - *Where part level testing is not possible, board level testing and/or system level testing may be the only alternative. In such cases, critical functional specifications should be tested and verified.*
  - *For advanced technologies, derating voltages below the manufacturer’s prescribed level may render the device inoperable.*

# JPL COTS Parts Risk & Reliability

## User & Application Guide – Excel-Based Appendix

- Created an Excel-based Appendix consisting of 30 examples of EEE Parts addressing reliability and risk factors
  - Caps, Diodes, Optoelectronics, Microcircuits, Resistors, Thermistors, Transistors
  - Part Type
  - Overview/General Construction
  - Circuit Applications
  - Common Failure Modes
  - Failure Mechanisms
  - Technology Trends
  - General Reliability
  - Recommendations for operation

D-1 Diodes								
Type	Overview/General Construction	Circuit Applications	Common Failure Modes	Failure Mechanisms	Technology Trends	Reliability	Recommendations	Relevant Graphs & Figures
Rectifier Diode	<p>Rectifier diodes can handle higher current flow than regular silicon diodes and are generally used in order to change alternating current into direct current. They are designed as discrete components or as integrated circuits and are usually fabricated from silicon and characterized by a fairly large P-N junction surface. This results in high capacitance under reverse-bias conditions. In high-voltage supplies, two rectifier diodes or more may be connected in series in order to increase the peak-inverse-voltage (PIV) rating of the combination.</p> <p><b>Planar diode structures</b></p> <p>Substrate diode      Well diode      Epi diode</p> 	<p>Mainly used to convert AC to DC. Used to regulate power in computers and the electrical power in motor vehicles. Also, used in battery chargers for rechargeable batteries, computer power supplies and vehicle batteries.</p>	<ul style="list-style-type: none"> <li>Thermal runaway</li> <li>Increases in leakage current</li> <li>Reduction in reverse breakdown voltage</li> <li>Open circuit</li> <li>Short circuit</li> </ul>	<ul style="list-style-type: none"> <li>Excessive power dissipation due to EOS (electrical over stress)</li> <li>ESD</li> <li>Degradation of passivation oxide</li> </ul>	<p>Mesa diode construction has better electrical behavior and are therefore more reliable.</p> 	<p>Diodes will experience displacement damage and ionizing damage in severe radiation environments, which can cause significant increases in reverse current. However, diodes show very little functional detriment up to about 10 kRads to 100.</p> <p>Advanced packaging for rectifiers:</p> 	<p>Industry standard derating for 10-yr reliability:</p> <ul style="list-style-type: none"> <li>Maximum <math>T_j = 0.75</math> (<math>T_{jmax} - 25^\circ\text{C} = 20^\circ\text{C}</math>)</li> <li>Forward Current <math>\leq 80\%</math></li> <li>Reverse Voltage <math>\leq 70\%</math></li> <li>Power <math>\leq 75\%</math></li> </ul>	

# UCLA Partnership

## Component Reliability Modeling Through the Use of Bayesian Networks and Applied Physics-based Models

**Elaheh Rabei**, Postdoctoral scholar, B. John Garrick Institute for the risk sciences, UCLA  
**Mark White**, Senior Member of the Technical Staff, CEO, NASA Jet Propulsion Laboratory, Caltech  
**Ali Mosleh**, Professor, B. John Garrick Institute for the risk sciences, UCLA  
**Subramanian Iyer**, Professor, Electrical Engineering Department, UCLA  
**Jason Woo**, Professor, Electrical Engineering Department, UCLA

Key Words: COTS, Reliability, Bayesian Network, Physics of Failure, Reliability Models

### SUMMARY & CONCLUSIONS

The objective of the work presented in this paper is to develop a practical methodology to support order of magnitude probabilistic prediction of Commercial Off-The-Shelf (COTS) components with little or no screening, qualification, or operational data. The physics-based approach to degradation/failure modeling of dominant failure mechanisms include: Time-Dependent-Breakdown-Defect (TDBD), Hot-Carrier Injection (HCI), Negative Bias Temperature Instability (NBTI) and Electromigration (EM). Moreover, it is crucial to consider other external factors that may eventually reduce the reliability of the device. These factors vary based on the fabrication, process, design and the product itself. This paper proposes an approach to identify and integrate all of the relevant qualitative and quantitative information using Bayesian Networks (BNs). The ultimate goal is to develop and validate an infrastructure of methods and tools for order of magnitude reliability assessment on the range of available information including results of physical models, statistical evidence, and expert opinion. The method is demonstrated by assessing the reliability of SRAM chips.

### 1 INTRODUCTION

Due to the combination of lower cost, higher performance, and greater capabilities of COTS semiconductor technologies, these devices are becoming highly desirable for space systems, particularly CubeSats. This market continues to demand high reliability levels, with single digit failure rates in FIT units, where 1 FIT = 1 failure per 10<sup>6</sup> operating device hours. Traditional testing for parts qualification is expensive and has historically been conducted for each part type and technology. For lower cost missions, testing parts for every application and technology generation represents a prohibitively high proportion of a mission's budget. One potential solution is the development of effective modeling practices to support "virtual" part qualification that is technology independent. In order to promote advanced technologies, which improve circuit

performance while easing budget constraints, such modeling practices must leverage information provided by COTS vendors and manufacturers. These information sources include data and specification sheets, part macro models, simulation models, and process design knowledge. Vendor data coupled with novel approaches for capturing environmental effects mechanisms, e.g., numerical methods, device and circuit simulation with MATLAB, SPICE, or similar simulation platforms, may facilitate the development of novel techniques. These techniques are accurate enough to predict component reliability, and ultimately ensure technology-independent component performance within specification at much lower costs.

This paper presents a methodology to estimate the reliability of COTS components by incorporating both physics-of-failure (PoF) as well as other external factors that eventually affect the reliability of the part. The main challenge here is the lack of experimental data for the particular COTS components of interest. Therefore, it is crucial to identify and integrate any sources of information available. In this paper, an expert-based Bayesian Network framework is introduced to provide a vehicle for integrating different sources of uncertain information to estimate the reliability of COTS electronic semiconductor devices. The core of the probabilistic inference engine is Bayes theorem, which enables full consideration of uncertainties in developing the distribution of a reliability metric, given a set of use conditions. To more accurately evaluate constituent components of a design and to determine their integral failure rates, the Bayesian Network (BN) methodology will be exercised in combination with physics-based reliability models that take into account PoF based wearout mechanisms. Wearout of complex semiconductor devices may be attributed to either, or both, dependent and independent failure mechanisms.

A novel approach to uncertainty assessment of the performance attributes and reliability of the constituent parts of a subsystem is virtual qualification, or qualification by simulation. BN models can also be used to capture information



## COTS Parts Reliability Assessment

Jason Woo\* ([woo@ee.ucla.edu](mailto:woo@ee.ucla.edu))  
 Ali Mosleh\* ([mosleh@ucla.edu](mailto:mosleh@ucla.edu))  
 Subramanian (Subu) Iyer\* ([s.s.iyer@ucla.edu](mailto:s.s.iyer@ucla.edu))

### Agenda:

- Scope
- Methodology
- Preliminary case studies
  - ADC
  - DRAM
- Moving Forward
- Reliability Estimation

Elaheh Rabei\*  
 Allen Chien\*  
 Steven Moran\*  
 Lixian Huang \*

\*Center for Heterogeneous Integration and Performance Scaling  
 \*Garrick Institute for the Risk Sciences

UCLA ENGINEERING  
 Henry Samueli School of  
 Engineering and Applied Science  
 Birthplace of the Internet

CHIPS  
 CENTER FOR HETEROGENEOUS INTEGRATION  
 AND PERFORMANCE SCALING

The Garrick  
 Institute for the  
 Risk Sciences



B. John Garrick Institute for the Risk Sciences  
 UCLA ENGINEERING

UCLA

## Commercial Off-The-Shelf (COTS) Usage in Space Systems: Part Reliability Analysis

Elaheh Rabei and Ali Mosleh  
 HAO-YU CHIEN, Jason Woo, Subramanian S. Iyer  
 UCLA  
 Presented at  
 JPL Review Meeting  
 August 24<sup>th</sup>, 2018

UCLA ENGINEERING  
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 CENTER FOR HETEROGENEOUS INTEGRATION  
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National Aeronautics and Space Administration



## Commercial Off-The-Shelf (COTS) Parts Risk & Reliability User & Application Guide

OSMS EP Investment Initiative  
 Office of Safety and Mission Success

Dr. Mark White

Jet Propulsion Laboratory  
 California Institute of Technology  
 Pasadena, California

NASA WBS: XXXXXXXXXX  
 JPL Project Number: E5XINV-OSMS EP INVESTMENTS  
 Task Number: EP.07.03-COTS in SPACE HW REL

Jet Propulsion Laboratory  
 4800 Oak Grove Drive  
 Pasadena, CA 91109

<http://xxxx.nasa.gov>

## Technology Road Mapping Meeting

Mark White  
 Caltech  
 6/27/17

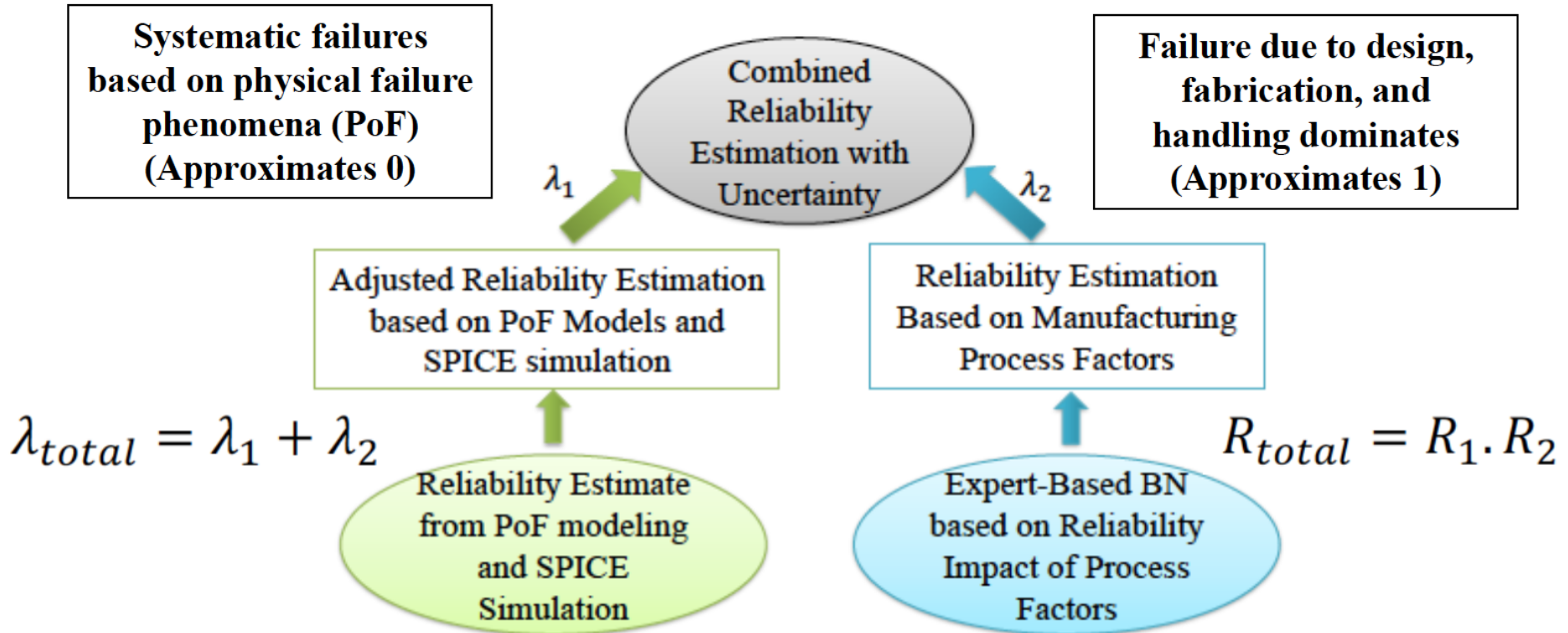
Type	Overview/General Comments	COTS Description	Current Failure Modes	Technology Road	Reliability	Recommendations	Advanced Graphs of Figure
SRAM	SRAM is the most common memory device used in CubeSats. It is typically used for volatile memory. The failure rate is high, but it is generally accepted that it is the most reliable memory device available. The failure rate is typically 10 <sup>-6</sup> to 10 <sup>-7</sup> FIT.	SRAM is a type of memory that stores data as long as power is supplied. It is typically used for volatile memory. The failure rate is high, but it is generally accepted that it is the most reliable memory device available. The failure rate is typically 10 <sup>-6</sup> to 10 <sup>-7</sup> FIT.	SRAM is a type of memory that stores data as long as power is supplied. It is typically used for volatile memory. The failure rate is high, but it is generally accepted that it is the most reliable memory device available. The failure rate is typically 10 <sup>-6</sup> to 10 <sup>-7</sup> FIT.	SRAM is a type of memory that stores data as long as power is supplied. It is typically used for volatile memory. The failure rate is high, but it is generally accepted that it is the most reliable memory device available. The failure rate is typically 10 <sup>-6</sup> to 10 <sup>-7</sup> FIT.	SRAM is a type of memory that stores data as long as power is supplied. It is typically used for volatile memory. The failure rate is high, but it is generally accepted that it is the most reliable memory device available. The failure rate is typically 10 <sup>-6</sup> to 10 <sup>-7</sup> FIT.	SRAM is a type of memory that stores data as long as power is supplied. It is typically used for volatile memory. The failure rate is high, but it is generally accepted that it is the most reliable memory device available. The failure rate is typically 10 <sup>-6</sup> to 10 <sup>-7</sup> FIT.	SRAM is a type of memory that stores data as long as power is supplied. It is typically used for volatile memory. The failure rate is high, but it is generally accepted that it is the most reliable memory device available. The failure rate is typically 10 <sup>-6</sup> to 10 <sup>-7</sup> FIT.

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# Combined Reliability Estimation and Uncertainty

COTS Reliability Estimation based on Two Main Types of Contributing Factors

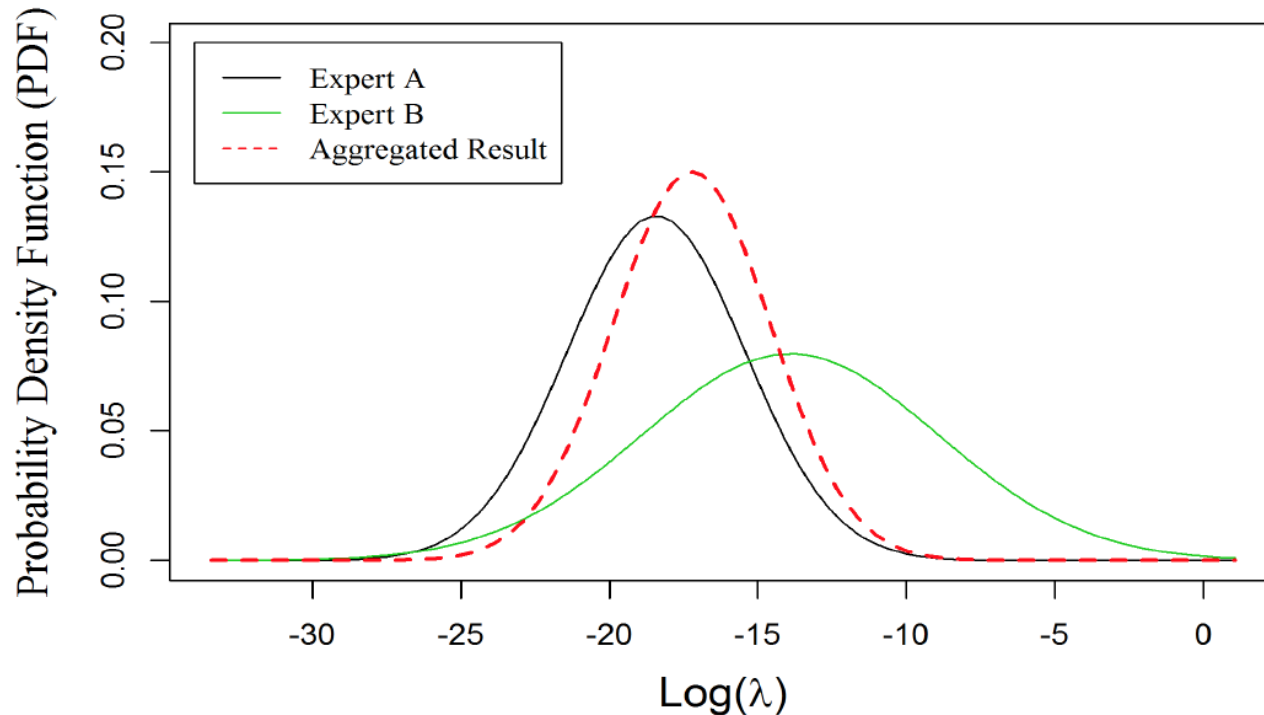


*IC failures are likely to be due to random defects introduced during the manufacturing of the chips or during packaging and handling instead of wearout*



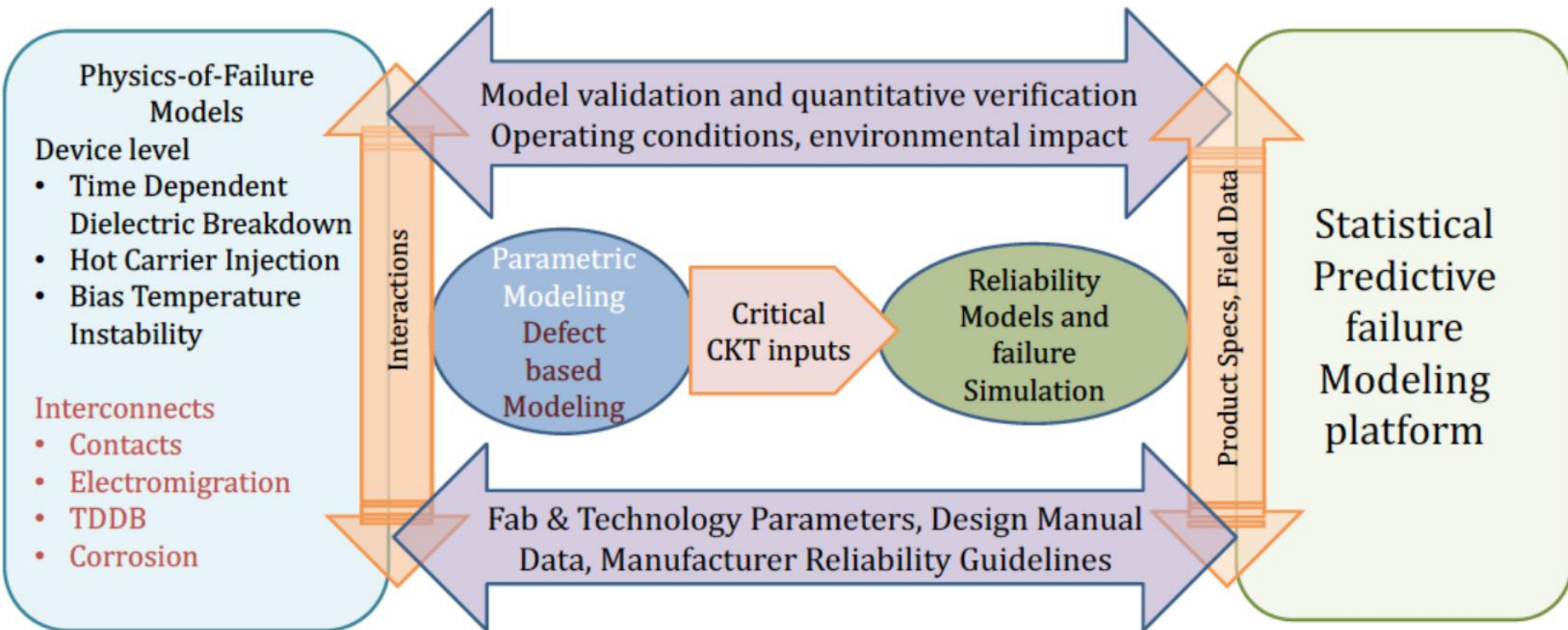
# Simulation Tools

- **Simulation Tool:** Developed initial version of R-based simulation tool to model PDF / Shape of Expert Opinion inputs based on semiconductor Process, Fab, Product & Design Factors
  - Given Expert input 1-n
  - S/W provides Aggregate Distribution



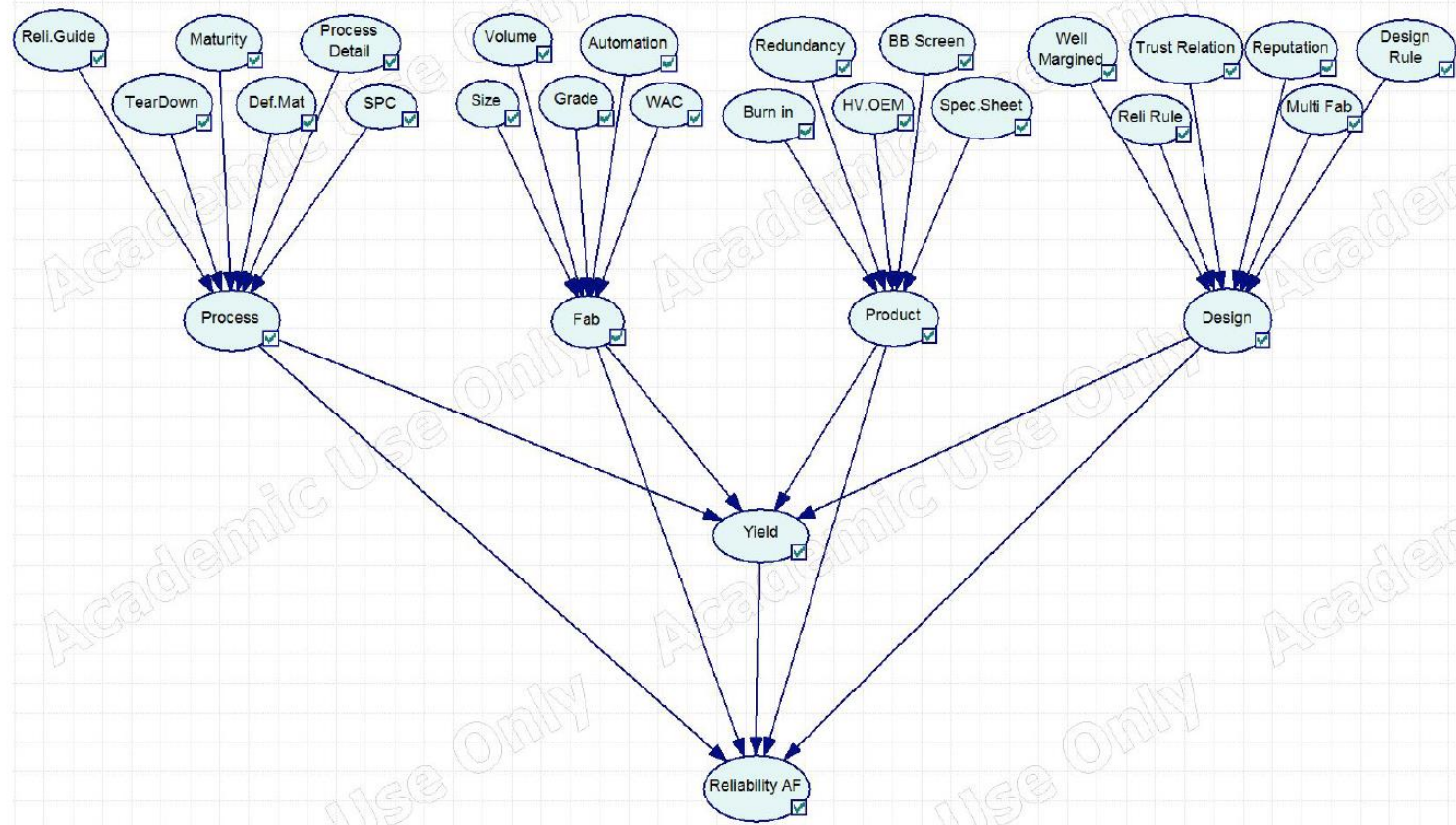
**Bayesian Posterior Distribution of Failure Rate based on Fusion of Expert Estimates**

# Device-Level Methodology



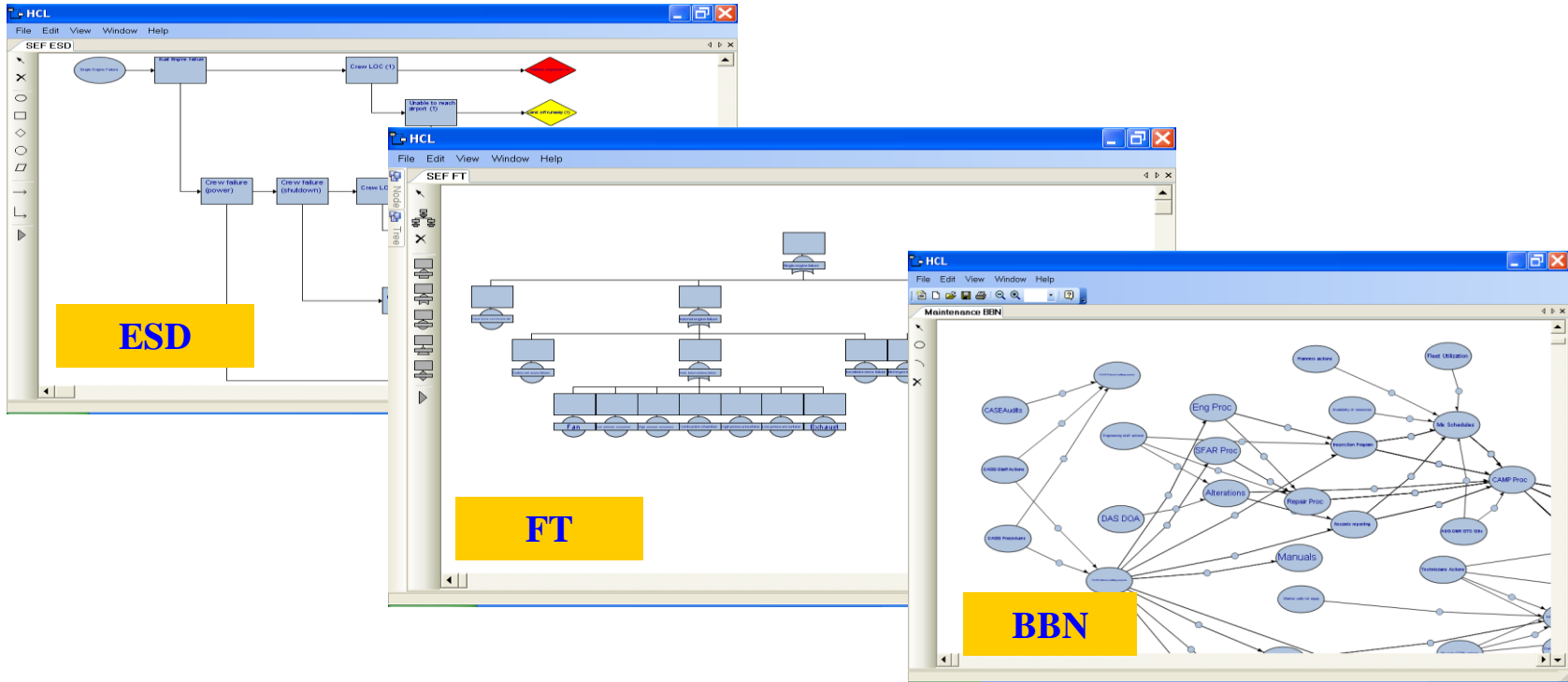
# Expert-Based Bayesian Network

When the Bayesian network model is fully defined by field experts, the analyst can apply it to a particular manufacturer and part of interest by selecting the states of each node with regard to its characteristics.

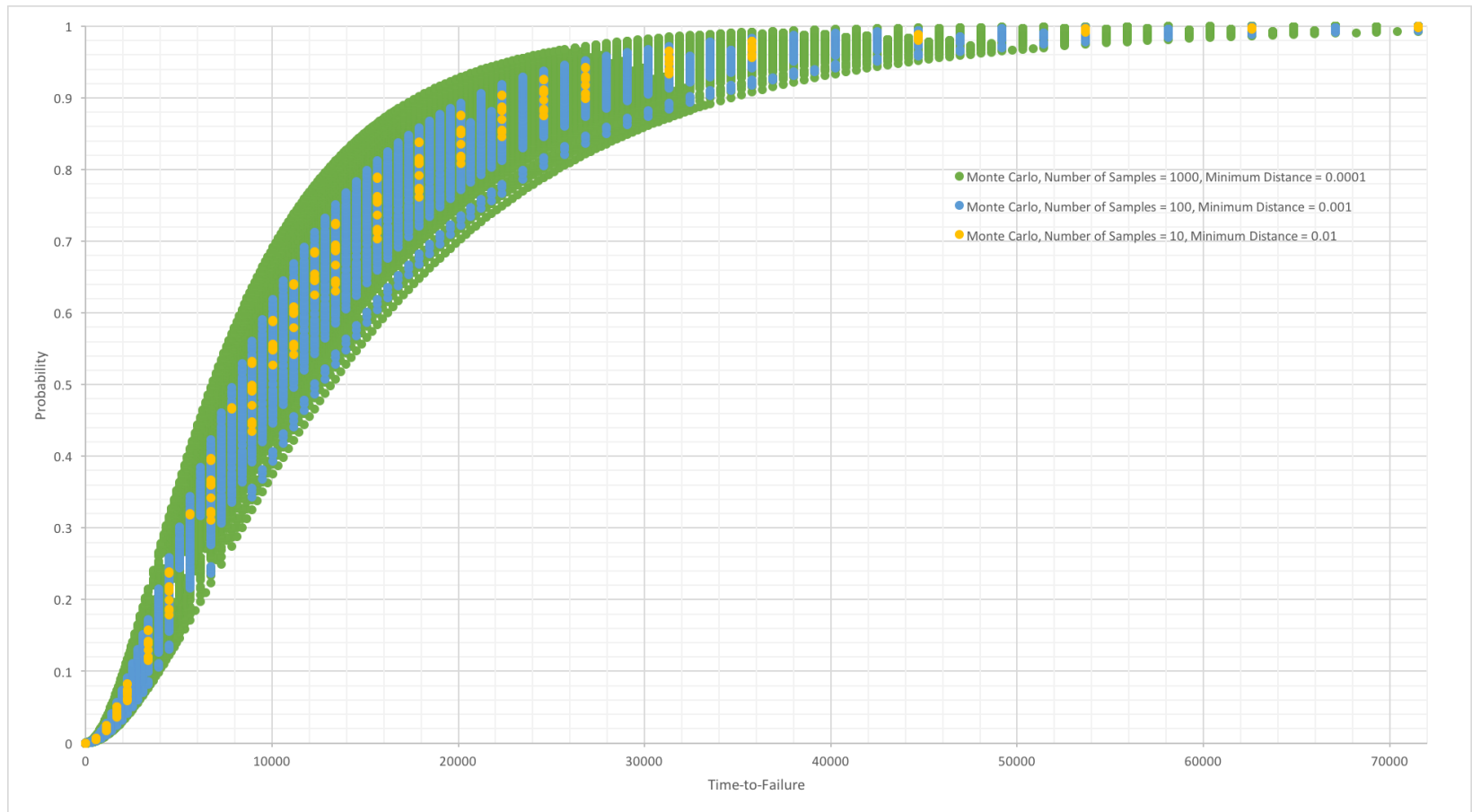




# COTS System-Level Reliability IRIS Logic Modeling Capability



# Time-to-Failure Propagation with Parameter Uncertainty (Simulated)



# Lunar Flashlight Mission Overview

## Objectives

◆ **Locate potential surface ice deposits in the Moon's south polar permanently shadowed craters.**

– Strategic Knowledge Gaps (SKGs):  
Composition, quantity, distribution, form of water/H species and other volatiles associated with lunar cold traps.

## Teaming

- ◆ *JPL-MSFC*
- ◆ *S/C (6U - 14 kg): JPL*
- ◆ *Mission Design & Nav: JPL*
- ◆ *Propulsion: MSFC*
- ◆ *Payload: 4 Lasers and 4-band point reflectometer (1-2 microns) - JPL*
- ◆ *I&T: JPL*

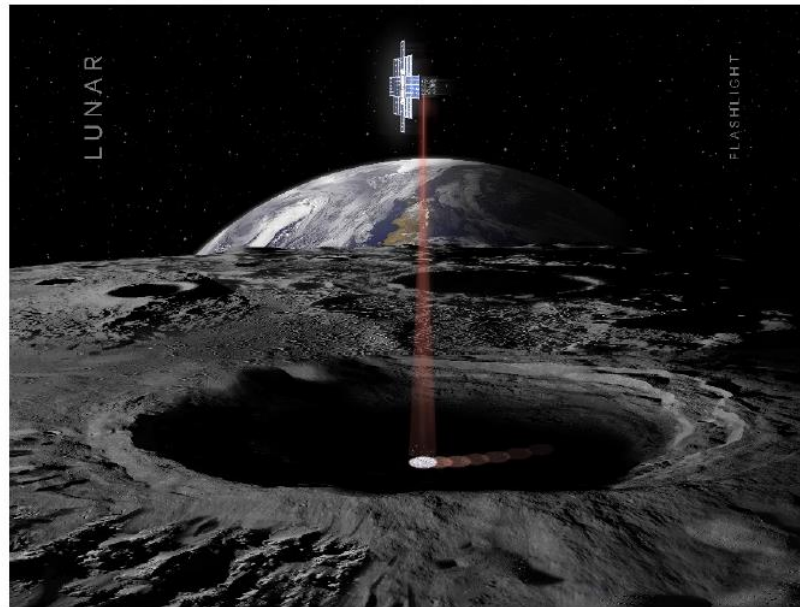
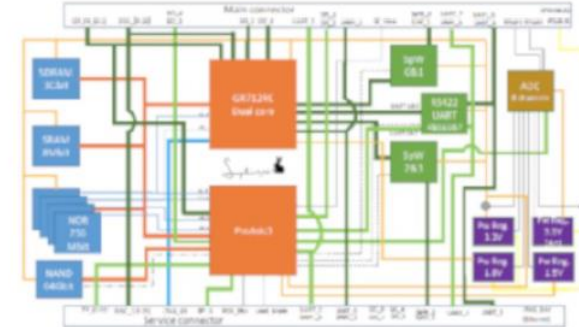
**Lunar Flashlight**— shining a light into the dark corners of our Moon

Launch: SLS flight EM-1 plans to carry up to 12 cubesats into lunar space in 2018]



# Test Case: Lunar Flashlight C&DH

- **Objective to exercise and validate models**
  - **Small part list and simple design makes problem tractable**
  - **Engineering models will be used for reliability and radiation testing**
  - **Eventual flight will provide additional validation**
- 
- A satellite is shown in space, with the Earth's horizon visible below it. The word "LUNAR" is written vertically in white capital letters on the left side of the image. The satellite has a central body with several rectangular panels extending from it. A red laser beam is directed from the satellite towards the Earth's surface. The background is a dark, starry space.



## Lunar Flashlight (6U) NIR laser

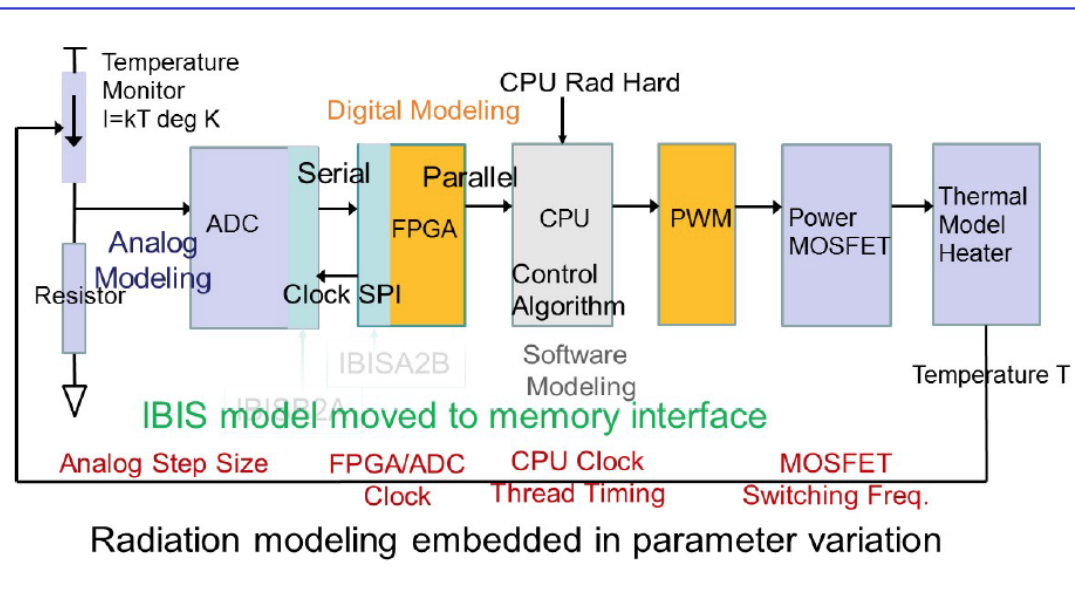
# Anticipated Results

First development of a “virtual assessment modeling framework” for COTS systems

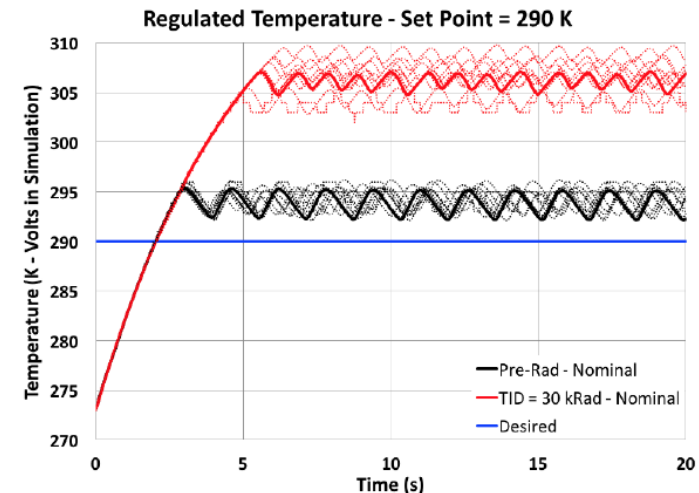
=> *New process development within 5X that will benefit JPL missions*

## Example of modeling flow developed

Temp. control loop within Sphinx C&DH



Closed-loop simulation results



Monte Carlo analysis included

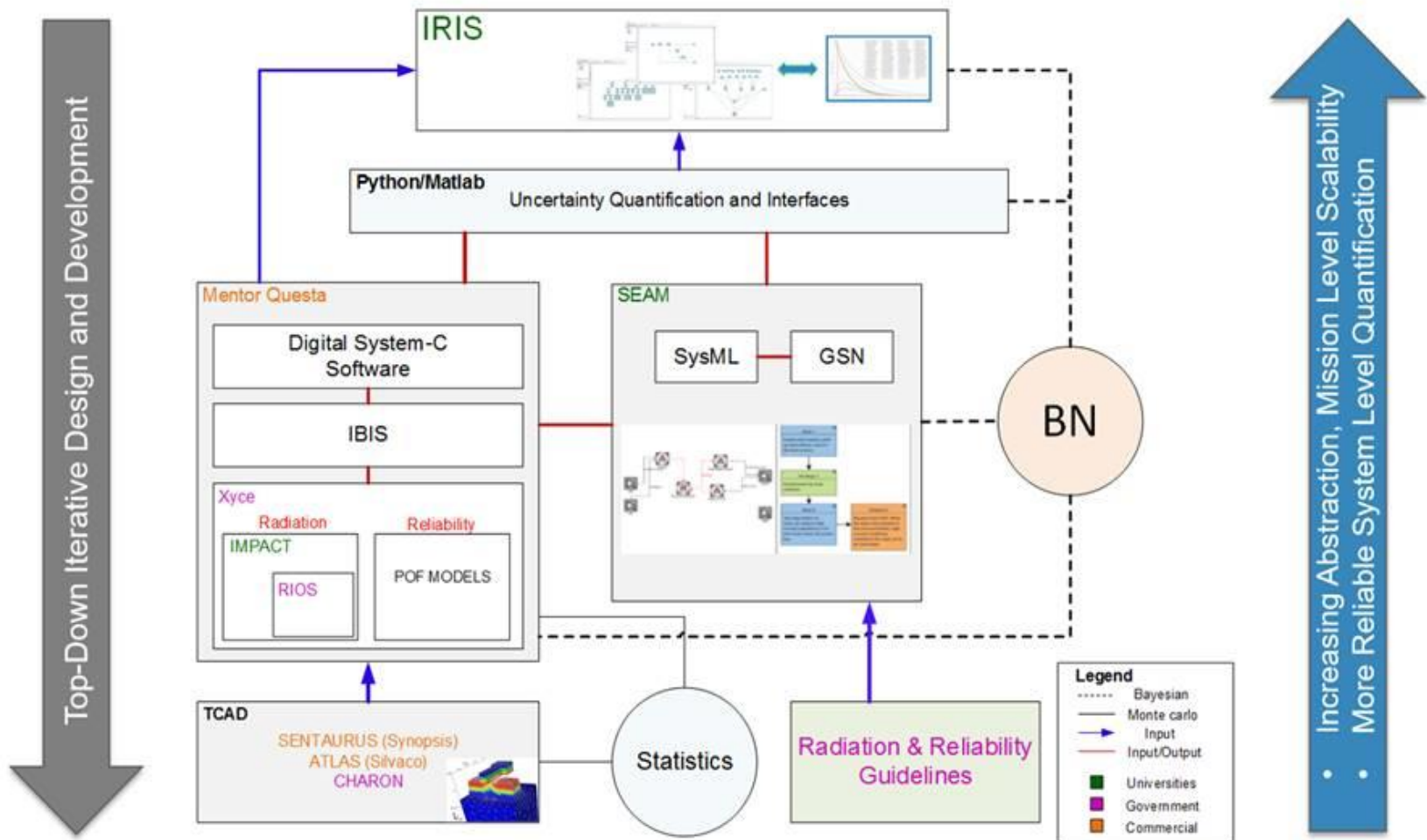
# Modeling Tools

## (Notional)

Abstraction	Domain	Domain Specific Tools	CrossCut Tools					
<div><div>H</div><div>L</div><div></div></div>	System/Requirements	SysML	P Y T H O N	M a t l a b				
	Functional	Orchestra (SNL) SysC			D a k o t a	Q u e s t a	I M P A C T	M R E D
	Behavioral	IBIS						
	Circuit	Xyce (SNL) Gateway X-SPICE Cadence						
	TCAD	Charon (SNL) Atlas (Silvaco) RIOS (SNL) Sentaurus (Synopsis)						
					SNL	VU	ASU	VU



# Modeling Tool Integration (Proposed)



# In Summary

- NASA has used commercial parts successfully in spacecraft, including mission critical applications. In the past, this was achieved through meticulous selection, screening and qualification.
- Alternative methods must be developed to assure low risk and sufficient reliability for the mission application.
- The development of modeling tools and a framework are becoming paramount in the evaluation of COTS-based Spacecraft Systems -  
*Virtual Qualification:*
  - Transistor
  - Component
  - System

